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NAVAL POSTGRADUATE SCHOOL
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THESIS

Resonator Measurements Of Acoustic Characteristics
Of Some Marine Crustaceans:
A Laboratory Experiment

by

Fred Joseph Mallgrave III

Thesis Advisors: H. Medwin
E. Haderlie
J. Novarini

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RESONATOR MEASUREMENTS OF ACOUSTIC CHARACTERISTICS OF SOME MARINE CRUSTACEANS: A LABORATORY EXPERIMENT

by

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ABSTRACT

Sound absorption due to single marine crustaceans was measured employing reverberation chamber techniques in the laboratory. Viscous and thermal losses were measured separately by varying the position of the absorbing body in the sound field. Only primary axial modes were employed and discreet frequencies were utilized in the range 1150 Hz to 3200 Hz by varying the height of the water column. Absorption cross sections (σ) were determined for both the thermal and viscous effects for two species of crustaceans (*Sergestes similis* and *Pasiphea pacifica*) which are prominent members of the scattering layer present in Monterey Bay, California. Values of σ due to viscous effects ranged from 0.152×10^{-5} to 1.042×10^{-5} m^2 whereas σ due to thermal losses varied from 0.311×10^{-5} to 1.670×10^{-5} m^2 . These values of σ resulted from measured viscous absorption coefficients of 3.19 to 8.65 dB/km and thermal absorption coefficients of 5.93 to 11.88 dB/km. These values resulted from a laboratory concentration of one specimen in 0.002 to 0.007 m^3 of water.

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ACKNOWLEDGEMENTS

In the course of this experiment many diverse fields of interest were encountered. Therefore, the help of many people was solicited. For the inception of the idea and expert laboratory guidance I would like to especially thank my advisor, Professor Herman Medwin. My co-advisor, Professor Eugene Haderlie, gave me guidance on specimen collection as well as providing the all-important species identification.

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I. INTRODUCTION

The propagation of sound in the ocean is, of course, affected by the inhomogeneities of the medium. The effects of temperature, salinity, and pressure variations on sound propagation have been well studied. The suspension of matter within the medium will also cause attenuation. Included in this suspended matter are the biota, particuarly plankton.

This report concentrates on two prominent members of the zooplankton community, both crustaceans, and their role in sound attenuation. A laboratory experiment was carried out to study one of the components of this phenomenon, namely absorption. Scattering, the second component of attenuation, was not addressed in this report. As this study was conducted in Monterey, California, the species available were <u>Euphausia</u> <u>pacifica</u>,<u>Sergestes</u> <u>similis</u> and other prawns probably <u>Pasiphea</u> <u>pacifica</u>. Barham (1956) showed that <u>E. pacifica</u> <u>and</u> <u>S. similis</u> were major members of Monterey Bay's deep scattering layer. In addition, they are also quite abundant as shown in <u>CalCOFI</u> <u>Atlas</u> <u>Number</u> <u>5</u>.

Since the crustaceans , once caught, can be maintained easily in the laboratory, prolonged testing is feasible (Lasker and Theilaker, 1965).

Because of the small size of the specimens, resonant cavity measurements of attenuation as measured through time decay in the reverberation level seemed to be the most advantagous. A choice had to be made as to hard or soft wall cavities. Initial testing was made using a hard wall cavity, but the soft wall proved to have a higher Q and therefore better suited for measurements of the small absorption expected for small numbers of the specimens.

II. NATURE OF THE PROBLEM

The problem examined here was the effect of single marine crustaceans on sound absorption. The primary objective of the experiment was to determine the absorption cross section of the bodies at various frequencies.

Previous work on planktonic crustaceans using acoustic resonator cavity methods has been reported by Lebedeva (1965), who used single crustaceans of the families Sergestidae and Oplophoridae. The report only dealt with the relative bulk modulus (reciprocal of compressibility). Literature on the subject of acoustic characteristics of small crustaceans is rather scarce and, to this author's knowledge, no value of absorption cross section of individuals has been reported.

In addition, an attempt was made to measure the relative compressibility of the animals.

The speed of sound (c) in a fluid is determined by the density (ρ) and the compressibility (K) of the medium. The equation combining these variables is:

$$c^2 = \frac{1}{\rho k}$$

When absorbing bodies are introduced into the fluid, their specific compressibility (the volume change of a substance per unit volume) must be taken into account. The difference between the compressibilities of crustaceans and sea water, though not large, does contribute to sound attenuation (Enright 1963).

III. EQUIPMENT DESIGN AND THEORY

A. RECTANGULAR AND CYLINDRICAL CAVITIES

Since the resonant cavity approach was to be used, design was the next consideration. Initially a rectangular cavity, 8.5 in. by 8.5 in. by 24 in., was constructed out of one half inch thick steel. This formed a rigid wall cavity. The idea was to construct a cavity suitable for both laboratory and *in situ* measurements. Numerous measurements of reverberation time were taken at various frequencies. It was found that the reverberation time, which is directly proportional to the quality factor (or Q), of the cavity was too low to be of any use with small planktonic samples (generally under 500).

The next cavity investigated was a thin-walled Pyrex cylinder which measured roughly 18 inches high by 6 inches in diameter (wall thickness 0.125 in.). This would represent a soft-walled cylindrical cavity. The use of glass had the additional advantage of being able to see if bubbles were present. Bubbles, of course, would greatly degrade the measurement of the system Q. Other features of this cavity were that it contained no seams to interfere with symmetry, it had a flat bottom which made it well-suited for support or suspension, the boundary allows for pressure release, and finally the cavity was readily obtainable as a stock item with no modifications necessary. In order to eliminate the effects of bubbles, filtered, degassed synthetic sea water was used throughout the experiment. Degassed water was made by allowing the water to stand for long periods of time in a vacuum. Filtering was accomplished by the use of micropore filters.

B. THEORY

The theory presented can be found in most general acoustic textbooks such as Morse (1948) or Kinsler and Frey (1962).

The homogeneous wave equation in cylindrical coordinates:

$$\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2}{\partial \phi^2} + \frac{\partial^2}{\partial z^2} - \frac{1}{c^2}\frac{\partial}{\partial t^2}\right] P = 0 \qquad (1)$$

Solution in an isotropic medium:

$$p = \sin(m\phi)\ \sin(k_z z)\ J_m(k_r r)\ e^{-i\omega t} \qquad (2)$$

where:

$m = 0, 1, 2, \ldots$
ϕ = cylindrical angular coordinate
z = axial coordinate
r = radial coordinate
$k_z = \omega/c$ axial wave number
$k_r = \omega/c$ radial wave number
c = speed of sound (m/sec)
t = time (sec.)
$\omega = kc$, angular frequency
$k^2 = k_z^2 + k_r^2$

Boundary conditions:

Sound pressure at the walls was taken to be zero. That is, if the cylinder radius is a, and the length is L, then p

$\vec{=} 0$ at $r = a$ and at $z = 0$ and $z = L$.

then, $\sin(k_z L) = J_m(k_r a) = 0$

$$k_z L = l\pi \qquad l = 1, 2, 3, \ldots$$

$$k_r a = \pi\beta_{mn}$$

Solutions $\pi\beta_{mn}$ are found from the equation $J_m(\pi\beta) = 0$, or the zero crossings of the Bessel function. As to the subscripts on β, the n indicates the number of radial antinodes in each Bessel function of order m.

The resonant frequencies of the cavity may be calculated from:

$$f_{\ell mn} = \frac{c}{2\pi}\sqrt{\left(\frac{\ell\pi}{L}\right)^2 + \left(\frac{\beta_{mn}\pi}{a}\right)^2} \qquad (3)$$

Setting l equal to zero yields pure radial modes. By varying the order of the Bessel function and value of n the various radial modes can be calculated and labeled.

Setting $\beta_{mn}\pi = 0$ results in pure axial modes. The combination of radi[illegible] and axial modes naturally follows.

The efficiency with which a resonant system stores energy is termed the "quality factor" or Q. It can also be thought as the sharpness of resonance. The Q can be determined by:

$$Q = \frac{f_{\ell mn}}{\Delta f} \qquad (4)$$

where Δf = bandwidth of resonance peak taken at the half power points or $$Q = \frac{\pi}{\alpha\lambda} \tag{5}$$

where: α = spacial attenuation in nepers/m

λ = wavelength at f

1. Determination of Absorption and Compressibility

Sound absorption in a medium is due to three effects:

1. viscous losses
2. heat conduction losses
3. molecular exchange of energy (relaxation process)

The latter generally occurs at high frequencies and was not addressed specifically in in this experiment. Yet it must be noted that numerous organic compounds do exist within the bodies of crustaceans which may undergo this relaxation phenomenon and contribute to sound attenuation. Since small absorption was expected, viscous effects and heat conduction effects were assumed to act independently in producing attenuation.

Viscous losses occur due to relative motion between the absorbing body and the medium. (Of course, they also occur in the medium itself). This effect will predominate where velocity is at a maximum.

As the fluid and absorbing body are compressed their temperatures are raised and a local temperature gradient is established. The subsequent flow of heat by conduction leads to thermal losses (Kinsler and Frey,1962). Hence, this would be the predominant effect where velocity is at a minimum and acoustic pressure is at a maximum.

With this in mind it was determined to utilize only the axial modes of the cavity. With only an axial mode present, absorption due to viscous effects was measured at the nodal points (maximum velocity, minimum pressure). Thermal effects were measured at the antinodal positions (maximum pressure, minimum velocity). With a body at the antinode it was also possible to measure relative compressibility of the body.

a. Absorption (α)

For plane waves in a medium with uniform distribution of absorbers:

$$dI = -I_p S_a dx \tag{6}$$

where: dI = change of intensity
I_p = original plane wave intensity
S_a = absorption cross section per unit volume (1/m)

S_a also equals $N\sigma_a$, where N is the number of absorbing bodies per unit volume. And σ_a is the absorbtion cross section of each absorber (m^2).

is defined as:

$$\sigma_a = \frac{\text{TOTAL POWER ABSORBED}}{\text{INCIDENT PLANE INTENSITY}} \tag{7}$$

Integrating (6) from above:

$$I_x = I_p e^{-S_a x}$$

taking 10 log to get intensity level (IL) in decibels (dB) :

$$10 \log I_x - 10 \log I_p = - S_a \Delta x \, 10 \log e$$

or,

$$\Delta IL = 10 \log e \; S_a \Delta x$$

$$= 4.34 \; S_a \Delta x$$

the absorption per unit distance is given by:

$$\frac{\Delta IL}{\Delta x} = 4.34 \; S_a = 4.34 \; N\sigma_a \; \text{(dB/distance)}$$

This absorption per unit distance is commonly referred to as the logarithmic absorption coefficient (α) of the medium at a given concentration of absorbing bodies. Therefore,

$$\alpha = \frac{\Delta IL}{\Delta x} = N \sigma_a 10 \log e \quad \text{(dB/distance)} \quad (8)$$

In the determination of absorption through the reverberation chamber technique, it was more convenient to work with the absorption coefficient per unit time (dB/time), a , than with α . This parameter, a , was the actual experimentally measured value. The value for a follows from the definition of reverberation time. This was taken as the time for the sound level to decrease from its maximum amplitude to a value 50 dB less than maximum. The time for this decrease was recorded on the sound level recorder. Thus a is obtained by dividing 50 dB by the reverberation time or:

$$a = \frac{50\text{dB}}{\text{REVERBERATION TIME}} \quad (9)$$

The calculation of α follows by applying the speed of sound (c) , or

$$\alpha = \frac{a}{c} \quad \text{(dB/distance)}$$

The speed of sound was expressed in meters per second, thus α is given in dB per meter.

Since the medium is absorbent by itself, the fraction of the absorption coefficient due to the bodies (α_b) is obtained as follows:

$$\alpha_b = \frac{a_{wb}}{c} - \frac{a_w}{c} \qquad (10)$$

where the subscripts w and wb represent water only and water plus bodies respectively.

Certainly, α_b depends on the concentration of bodies in the water sample under consideration. Thus the absorption of a single absorber is best expressed through the absorption cross section, σ_a . From equation (8):

$$\sigma_a = \frac{\alpha_b}{10 \log e \ (N)}$$

Since in this experiment there was only one body in the volume , it follows that,

N = 1/volume of water column

therefore:

$$\sigma_a = \frac{\alpha_b}{10 \log e} \text{(volume of water column)} \qquad (11)$$

b. Compressibility (K)

$$K = \frac{\Delta V/V}{P}, \quad V = \text{volume}$$

$$c_w^2 = \frac{1}{\rho_w K_w} \tag{12}$$

$$c_{wb}^2 = \frac{1}{\rho_{wb}(K_w + K_b)} \tag{13}$$

subscripts: w (water only), b (body only), wb (water plus body)

f_w represents the tuned resonance frequency without bodies present. A body is introduced into the water and the system is re-tuned to resonance. f_{wb} represents this new frequency.

By using only the primary (first) axial mode the wavelength remains constant. That is, $\lambda_w = \lambda_{wb}$. Using the relation that $\lambda f = c$, the following holds true:

$$\frac{f_w}{f_{wb}} = \frac{c_w}{c_{wb}} = \sqrt{\frac{\rho_{wb}[K_w + K_b]}{\rho_w K_w}} \tag{14}$$

Assume $\rho_{wb} = \rho_w + \delta\rho$,that is, the density of the body constitutes a small perturbation in the water ,or,

$$\delta\rho << \rho_w$$

then,

$$\frac{f_w}{f_{wb}} \cong \sqrt{\frac{K_w + K_b}{K_w}} \tag{15}$$

where K can be obtained from equation (12).

Since equation (15) holds for a uniform distribution of bodies in the volume, the result must be multiplied by V'/V. Where V' = volume of the body and V = volume of the water.

C. CAVITY SUPPORTS

The object in choosing a proper support was to keep the sound energy in the cavity and not have it transmitted to the support. Therefore a support system of minimal area and bulk was a necessity. Since wire sling-like supports have been used successfully with glass spherical cavities (Leonard, 1950) this method was settled upon.

An aluminum ring (approximate diameter 10 in.) was fitted with four isolation mounts of the rubber dashpot type. These would insulate the base ring from the laboratory table. The top surface of the ring was fitted with four large bolts to serve as attachment points. Wire was strung between the posts forming an X-shaped surface. In this configuration the wire lent enough strength to support the water-filled cavity, but presented minimal surface area. The heavy posts served to reflect energy traveling along the wires back into the cavity. The support is represented in figure 1b.

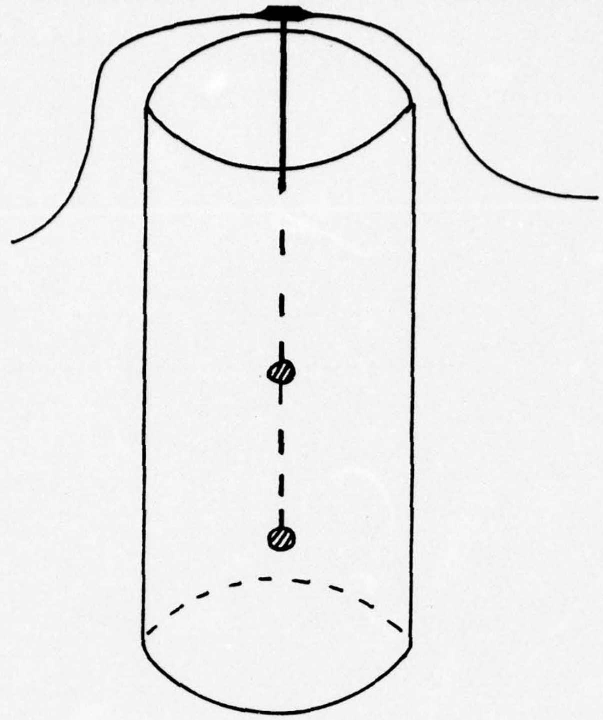
D. TRANSDUCERS

Initial testing consisted of introducing both the transducer and the receiving hydrophone into the cavity. Two LC-5 hydrophones were suspended along the axis of the cylinder. The reverberation times recorded in this configuration proved to be less than desired. The hydrophones themselves were causing the sound to scatter.

It was then decided to mount barium titanate transducers to the cavity exterior. Two 0.500 in. by 0.500 in. transducers were shaped to conform to the wall curvature and epoxied at the mid-height level and directly opposed to each other. This setup proved to be very satisfactory. A marked increase was noted in reverberation times. Both configurations are shown in figures 1a and 1b.

However, when it was decided to employ only primary axial modes both transducers were repositioned on the cylinder base (figure 2). In this configuration the axial mode could be driven more effectively and the water level could be lowered without affecting reception.

a.



b.

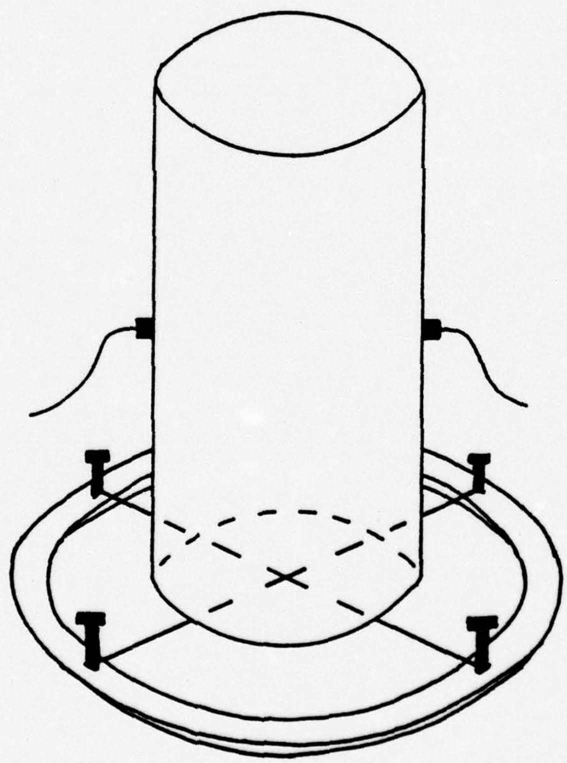


Figure 1 - PRELIMINARY CAVITY CONFIGURATIONS

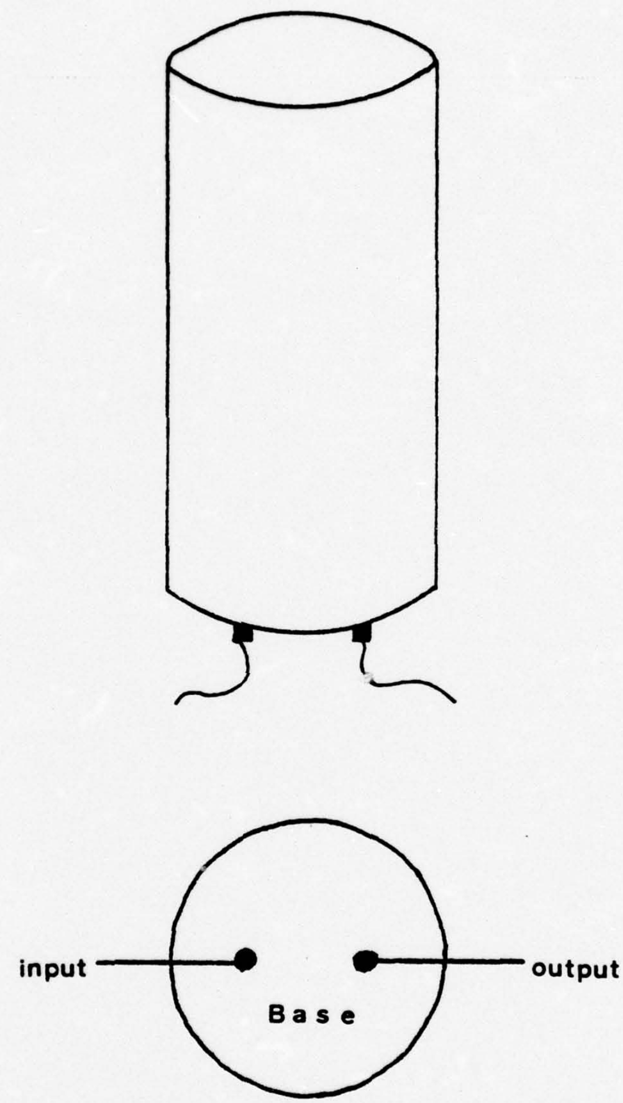


Figure 2 - FINAL CAVITY CONFIGURATION

IV. INSTRUMENTATION

A. SIGNAL TRANSMISSION

A sinusoidal signal was generated in a Hewlett-Packard 204C continuously-variable oscillator when searching for resonant modes was desired. Once modes were identified the signal was generated using a General Radio Digital Decade Frequency Synthesizer Type 1161-A.

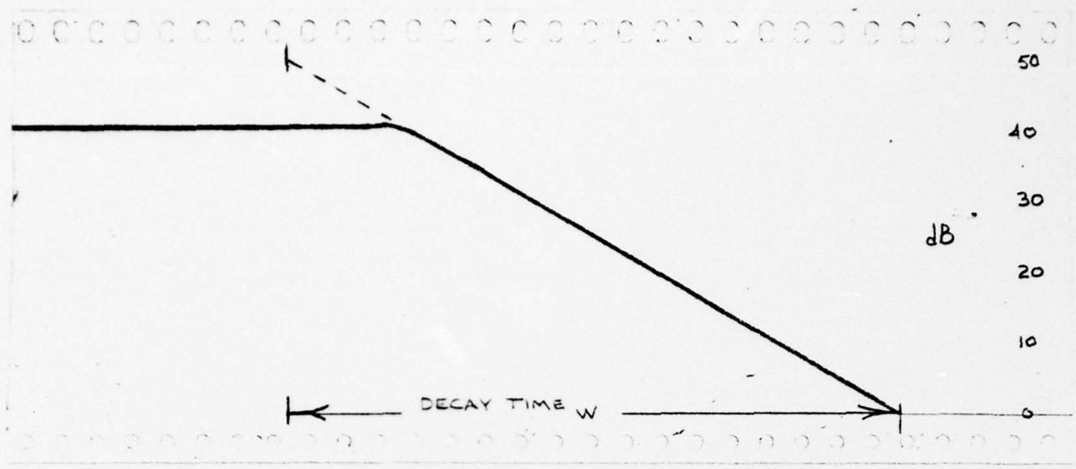
A General Radio Tone Burst Generator Type 1396-A was used to turn the signal on and off. Length of the pulse and the space between pulses was regulated by a timing signal generated by a Brüel and Kjaer Oscillator Type 1014. The resultant pulse was sent to the transducer via a Hewlett-Packard Model 467A Power Amplifier and was also used to trigger the oscilloscope (Tektronix Type 545). Refer to the block diagram in figure 4.

B. SIGNAL RECEPTION

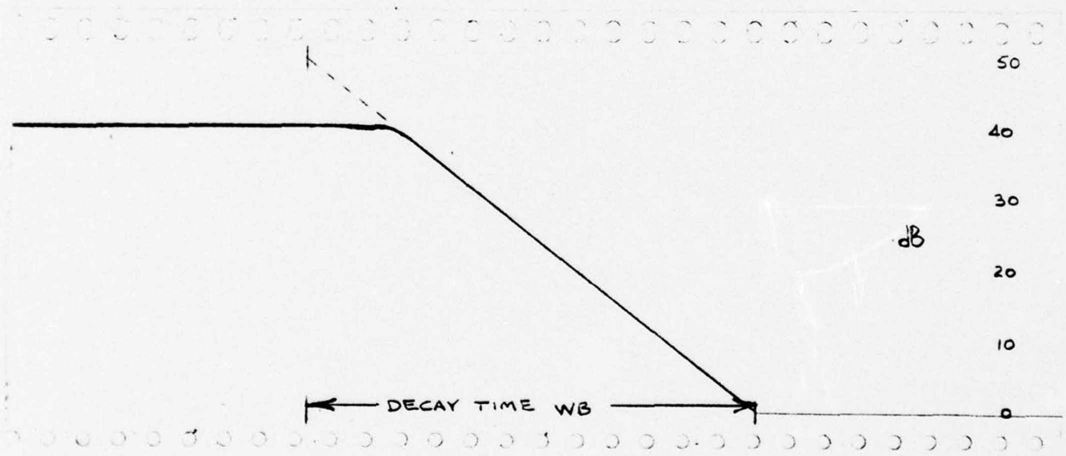
Sound was received at an identical barium titanate transducer and sent through two power amplifiers, Hewlett-Packard 466A and 467A. In this case the 466A was employed as a pre-amplifier. The intensity of the signal before amplification was approximately 3 to 5 millivolts so extreme care was be taken to shield all cables and connectors. The signal was then filtered through a

Khronhite Filter Model 13342 in the band pass mode then sent to the oscilloscope and a Bruel and Kjaer Level Recorder Model 2304.

The level recorder was fitted with a 50 db potentiometer so that full width of the record (50 mm.) represented a 50 dB decrease in sound level. The reverberation time was thusly recorded as the time for the signal to attenuate by 50 dB. Sample recorder outputs are displayed in figure 3. The receiving portion is also represented in figure 4. A photograph of the laboratory set-up is shown in figure 5.



without body



with body

Figure 3 - SAMPLE RECORDER OUTPUTS WITH INDICATED DECAY TIMES

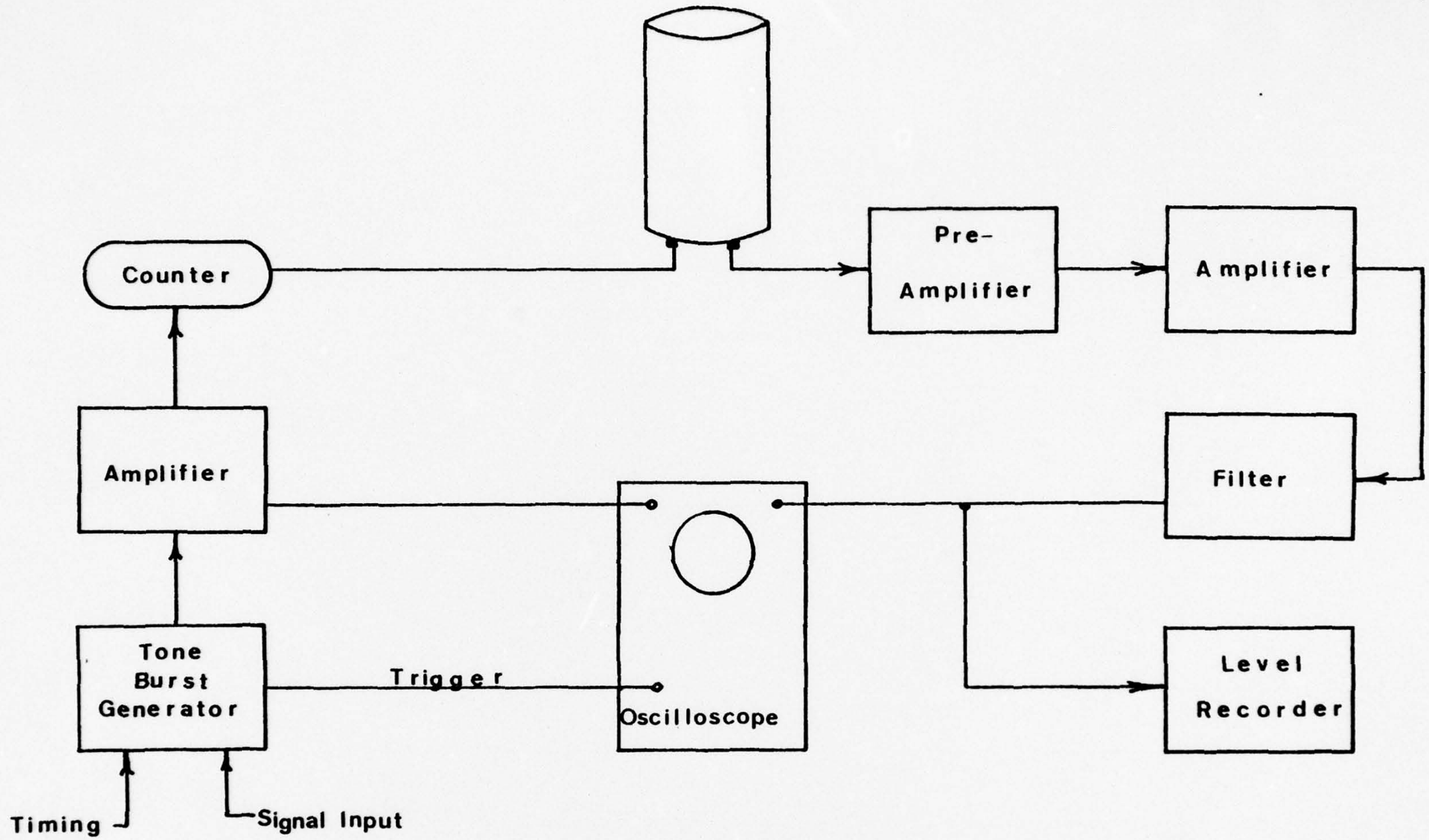


Figure 4. EXPERIMENTAL EQUIPMENT SCHEMATIC

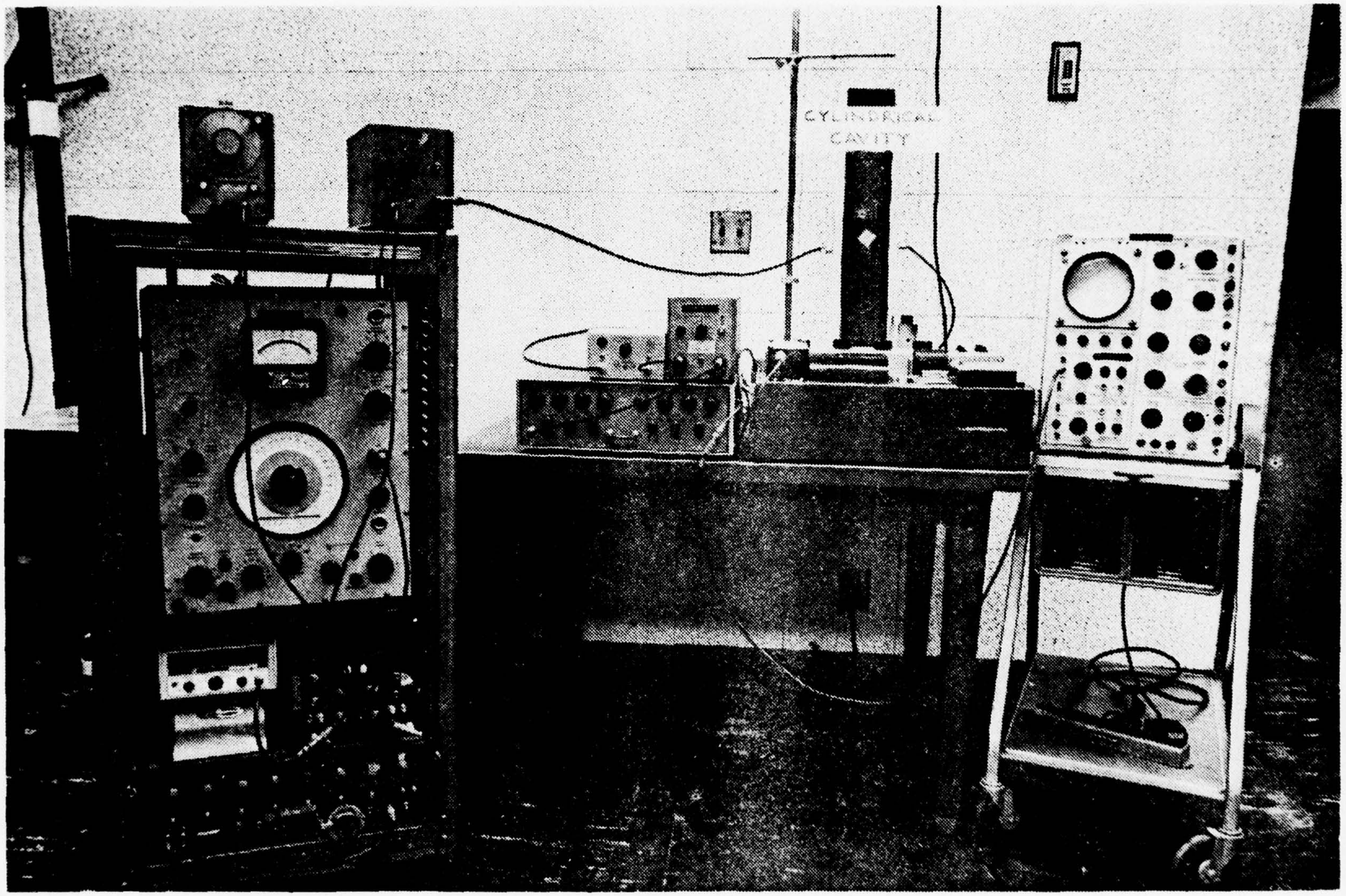


Figure 5. LABORATORY SET-UP

V. THE EXPERIMENT

A. ANIMAL COLLECTION

Collection of the specimens was made using a Tucker trawl aboard Research Vessel Acania (see figure 6). The net mouth measured six feet square with wide mesh tapering down to a coarse plankton net. One gallon glass jars were used for the cod end. Trawls were made in the morning with the net at a depth of 300 to 700 meters. Duration of each trawl was about 20 to 40 minutes. Retrieved jars were capped and stored in the ship's refrigerator until docking.

B. ANIMAL TREATMENT IN THE LAB

The specimens were transported directly to the laboratory where the crustaceans were separated from the remainder of the plankton. The crustaceans were placed in one quart specimen jars (1 to 2 per jar) and the sealed jars placed in a refrigerated salt water aquarium used as a constant temperature bath. Temperature was controlled at 10 degrees Celcius. The aquarium was covered to maintain a cold, dark environment. The specimens were fed *Artmia salina* larvae (commonly known as brine shrimp) daily. The larvae were hatched from dry eggs. Keeping the aquarium dark also served to deep the larvae in suspension and thus better available to the filter feeding crustaceans.

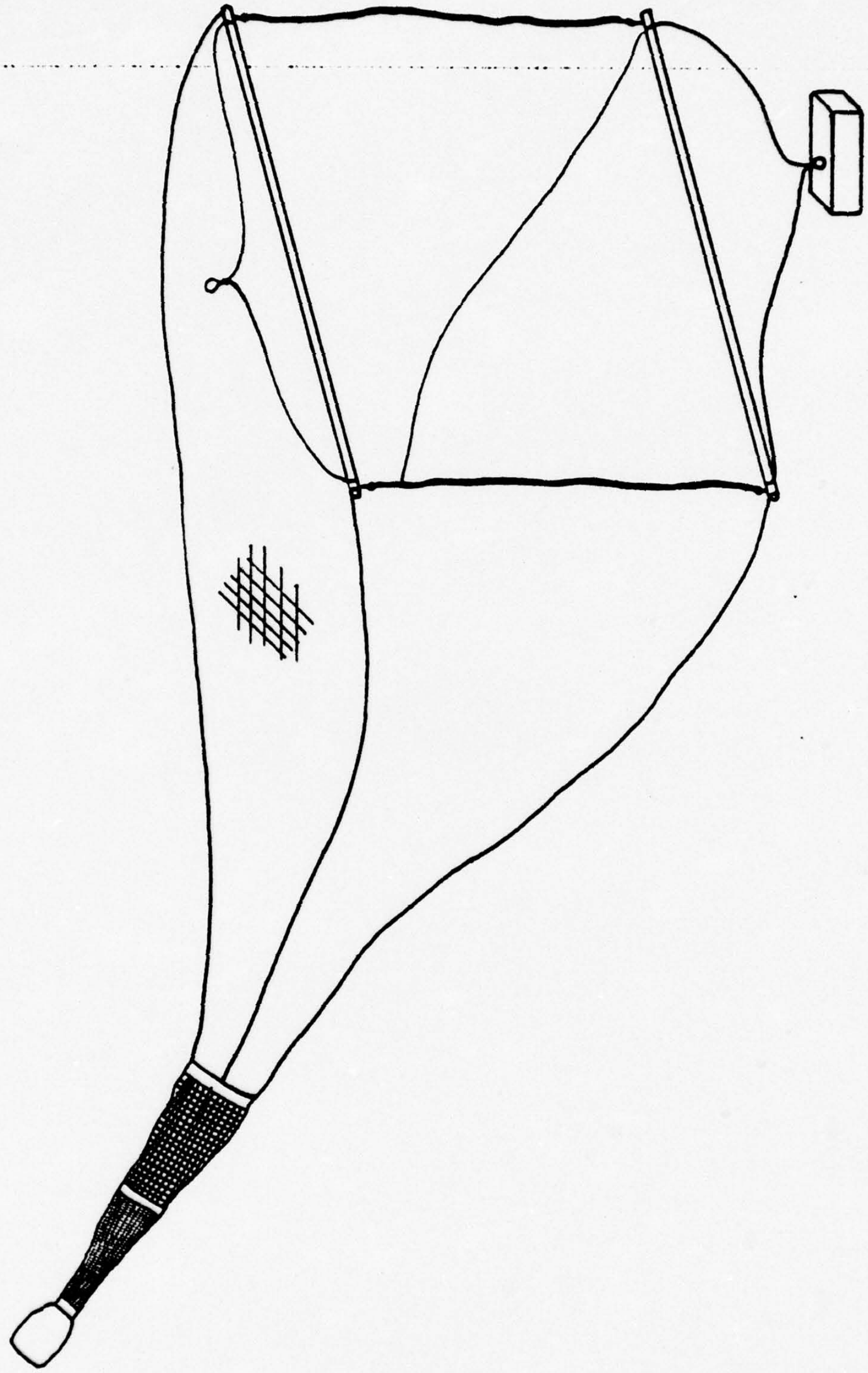


Figure 6 - TUCKER TRAWL

C. PROCEDURE

Because of the small size of the species *Euphausia pacifica* (about 15 mm) initial measurements were taken using multiple bodies. The animals were constrained in a small nylon sack which could maintain their orientation in the water column. However the cumulative effect of multiple animals along with the sack would not be conclusive. Therefore, the remainder of the experiment was conducted using the remaining two previously mentioned species. The larger prawns were investigated as single absorbers by suspending each on a thin wire at the desired location in the tank.

The cylinder was filled with the filtered and degassed synthetic sea water and the electronic equipment was allowed to warm up. The water remained at a constant temperature throughout the experiment, thus no variations in resonance frequency with temperature occurred. The oscillator was tuned to the primary axial mode. The water was probed with an LC-10 hydrophone to ensure that the primary mode was present and to find the exact location of the antinode. Resonance frequencies due to the glass only were known and avoided at all times during the experiment. The frequency was noted and decay times were recorded.

A single, live crustacean was selected and suspended on the wire. It was lowered to the first node and the cavity was re-tuned to resonance. The frequency and decay time were then recorded. The same procedure was followed while the animal was lowered to the antinode and the second node. Resonance frequency and decay time were determined again for the cylinder without the animal present to check for instrument drift.

The water level was then reduced to three quarters full and the experiment repeated. Subsequently the level was reduced to half and quarter full to give a range of four frequencies.

VI. RESULTS AND DISCUSSION

The results of the experiment are presented in Tables I through IV (Appendix A). Tables I and II display results for *Sergestes similis* and Tables III and IV show results for *Pasiphea pacifica.* Each table is divided into four main sections corresponding to each frequency examined. The frequency columns are further sub-divided into three sections indicating separate runs on different animals. The parameters listed are:

$\alpha^{(1)}_{vis}$ $\alpha^{(2)}_{vis}$ = viscous absorption coefficient measured at nodes 1 (top of the water column) and 2 (bottom of the water column) respectively.

α_{th} = thermal absorption coefficient measured at the antinode.

$\alpha^{(u)}$ $\alpha^{(1)}$ = absorption coefficients measured between the upper node (u) and the antinode, and the lower node (l) and the antinode.

The $\alpha^{(u)}$ and $\alpha^{(1)}$ measurements were only made at a few frequencies in order to serve as an experimental check. That is, these values should be less than or equal to the sum of the absorptions measured at the points where the maximum separate effects occur, the adjacent node and antinode. A look at the results shows that this does indeed hold true. Runs,other than (u),(l),where no value was listed produced results outside of acceptable experimental error and , therefore, were not included in the table.

The decay time and resonance frequency were determined with an accuracy of ±0.005 seconds and ±0.1 Hz respectively, leading to an error of less than 3% in the determination of both α and σ_a .

As was noted earlier, the absorption depends upon the concentration of absorbers. Therefore, the tabulated values of α must be viewed in that context. The experimental concentration corresponding to the four discreet frequencies was:

1150 Hz	1 absorber per 7.101×10^{-3} m^3
1420 Hz	1 absorber per 5.325×10^{-3} m^3
1940 Hz	1 absorber per 3.550×10^{-3} m^3
3200 Hz	1 absorber per 1.775×10^{-3} m^3

These are very high concentrations when compared to oceanic distribution of the species studied.

Estimates of naturally occuring concentrations in the sonic scattering layer are quite diverse. Hersey and Backus summarized the estimates of several authors in <u>The Sea</u> , Vol. 1 (1962) when they reported,

1 body per 10^4 m^3 (Raitt 1948)
1 body per 8.5×10^3 m^3 (Kanwisher and Volkman 1955)
1 body per 650 m^3 (Johnson, <u>et al</u> 1956)
Additionally, Lebedeva (1971) estimated 1 body per 10^2 to 10^3 m.

To determine values for absorption coefficients (α) for typical concentrations (N) it can either be calculated from equation (8),

$$\alpha = N \sigma_a 10 \log e$$

or, since the absorption coefficient (α_0) for a known concentration (N_0) was measured, then $$\alpha = \alpha_0 \frac{N}{N_0}$$

Typical values of α would be a small fraction of the reported laboratory value due to the difference in concentration of absorbers.

For example; with α_0 = 3.30 dB/km, N_0 = 1 per 7.101 x 10^{-3} m^3 and assuming N = 1 per 650 m, then α = 3.61 x 10^{-5} dB/km.

Regarding the main result of the experiment, the absorption cross section. In all cases the calculated value of σ thermal exceeds the value of σ viscous. In other words, the crustaceans studied present a larger (11% to 69%) crossection in compression than that due to relative motion.

It must also be observed that values of σ viscous calculated from different runs differ by approximately 3% when f = 1150 Hz and 1420 Hz and by approximately 25% when f = 1940 Hz and 3200 Hz. This deviation at the higher frequencies can be attributed, in part, to the fractional change in water in the cavity, hence the volume. That is, $\Delta V/V$. Since the chamber is one-half and one-quarter full when f = 1940 Hz and 3200 Hz respectively, a small change in volume , ΔV, at these frequencies would appear large when compared to the volume, V, of the chamber. Consequently a ΔV at the lower two frequencies (full and three-quarter full chamber) would have less effect. This change in volume might easily take place during filling, for example. The deviation in σ viscous might also be due to the change in dimension and properties of the body, since different specimens were used for each run. On the other hand, the values of σ viscous for a given specimen measured at different positions (1st node and 2nd node) are in excellent agreement which demonstrate the repeatability of the experiment.

An attempt was made to measure relative compressibility of the specimens. However, anomalous results were noted when compared with previous work (Enright 1963 and Lebedeva 1965). It was theorized that even though the water was filtered and degassed, small (less than 10 μm radius) bubbles were present (H. Medwin personal communication).[1] Using this postulated bubble size, the calculated bubble resonance frequency exceeded 300 kHz. Thus, where this would certainly not affect absorption because of the low frequency range of the experiment, it would affect compressibility. Therefore, results of compressibility were not reported.

[1] At Naval Postgraduate School, Monterey, California.

VII. SUGGESTIONS FOR FURTHER STUDY

It has been shown by this study that reverberation chamber techniques in the laboratory are quite suitable for examination of the small absorption cross sections encountered with planktonic crustaceans. It would be desirable to obtain both more data on the species studied, and on other species.

The same technique also lends itself to the determination of the compressibility of small marine animals. However, the presence of bubbles of any size invalidate the results. Therefore, future measurements must be made in a highly controlled environment. Water must be degassed thoroughly by heating or by employing sonic methods while being evacuated.

Decay time measurements lend themselves readily to digital methods of recording. Hence, future studies should include a digital capability. Experiments conducted in this manner would be able to collect large amounts of data.

APPENDIX A

TABLES OF RESULTS

	1150 Hz			1420 Hz			1940 Hz			3200 Hz		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
$\alpha_{vis}^{(1)}$	-	3.19	3.30	8.65	8.65	8.40	3.88	3.88	4.18	5.73	5.73	4.25
$\alpha_{vis}^{(2)}$	-	3.19	3.30	8.65	8.65	8.40	3.22	3.88	4.18	5.73	5.73	4.25
α_{th}	-	10.22	8.82	10.56	10.56	10.25	5.93	5.93	6.23	6.40	7.08	7.61
$\alpha^{(u)}$	-	-	5.03	-	-	9.13	-	-	-	-	-	-
$\alpha^{(1)}$	-	-	5.03	-	-	9.45	-	-	-	-	-	-

TABLE I - Absorption, dB/km, for *Sergestes similis*

	1150 Hz			1420 Hz			1940 Hz			3200 Hz		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
$\sigma^{(1)}_{vis}$	-	0.521	0.540	1.042	1.042	1.030	0.318	0.318	0.343	0.234	0.234	0.234
$\sigma^{(2)}_{vis}$	-	0.521	0.540	1.042	1.042	1.030	0.263	0.318	0.343	0.234	0.234	0.234
σ_{th}	-	1.670	1.445	1.272	1.272	1.256	0.485	0.485	0.515	0.262	0.290	0.311
$\sigma^{(u)}$	-	-	0.823	-	-	1.119	-	-	-	-	-	-
$\sigma^{(1)}$	-	-	0.823	-	-	1.165	-	-	-	-	-	-

TABLE II - Absorption Cross Section, $m^2 \times 10^5$, for Sergestes similis

	1150 Hz			1420 Hz			1940 Hz			3200 Hz		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
$\alpha_{vis}^{(1)}$	5.55	5.51	5.85	-	4.18	4.49	4.91	4.18	4.49	5.69	5.19	3.72
$\alpha_{vis}^{(2)}$	5.55	4.79	5.85	-	4.18	4.49	4.91	4.18	4.49	5.69	6.62	4.49
α_{th}	8.28	7.71	9.81	-	7.31	9.34	7.18	6.38	6.87	11.88	11.30	9.34
$\alpha^{(u)}$	7.17	6.23	8.19	-	5.02	5.67	-	-	-	-	-	-
$\alpha^{(1)}$	7.17	5.51	7.40	-	5.02	5.67	-	-	-	-	-	-

TABLE III - Absorption, dB/km, for <u>Pasiphea pacifica</u>

	1150 Hz			1420 Hz			1940 Hz			3200 Hz		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
$\sigma_{vis}^{(1)}$	0.907	0.900	0.957	-	0.513	0.601	0.401	0.342	0.367	0.233	0.212	0.152
$\sigma_{vis}^{(2)}$	0.907	0.783	0.957	-	0.513	0.601	0.401	0.342	0.367	0.233	0.271	0.184
σ_{th}	1.355	1.261	1.604	-	0.897	1.146	0.587	0.522	0.562	0.486	0.462	0.382
$\sigma^{(u)}$	1.173	1.019	1.340	-	0.616	0.696	-	-	-	-	-	-
$\sigma^{(1)}$	1.173	0.900	1.210	-	0.616	0.696	-	-	-	-	-	-

TABLE IV - Absorption Cross Section, $m^2 \times 10^5$, for <u>Pasiphea pacifica</u>

LIST OF REFERENCES

1. Barham, E. G., The Ecology of Sonic Scattering Layers in the Monterey Bay Area, California , Ph.D. Thesis, Stanford University, 1956.

2. Brinton, E., CalCOFI Atlas No. 5 , State of California Marine Research Committee, 275 pp., 1967.

3. Enright, J. T., Estimates of the Compressibility of Some Marine Crustaceans, Limnology and Oceanography, 8(4), pp. 382-387, 1963.

4. Hersey, J. B. and Backus, R. H., Sound Scattering by Marine Organisms, in: The Sea, Vol. 1 , Interscience, pp. 499-507, 1962.

5. Kinsler, L. E. and Frey, A. R., Fundamentals of Acoustics, 2nd Ed., Wiley, 524 pp., 1962.

6. Lasker, R. and Theilaker, G. H., Maintenance of Euphausiid Shrimps in the Laboratory, Limnology and Oceanography, 10, pp. 278-288, 1965.

7. Lebedeva, L. P., Measurement of the Bulk Modulus of Elasticity of Animal Tissues, Soviet Physics-Acoustics, 10(4), pp. 410-411, 1965.

8. Lebedeva, L. P., Sound Scattering by Planktonic Animals which are Small Relative to the Wavelength of Sound, Oceanology, 11(6), pp. 890-895, 1971.

9. Morse. P. M., Vibration and Sound, McGraw-Hill, 468 pp, 1948.

10. University of California, Los Angeles, Technical Report

No. I, The Attenuation of Sound in Liquids by a Resonator Method, by R. W. Leonard, 16 pp., June, 1950.

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